Quantitative Monographs

Does your risk model forecast your risk?

Equities

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Risk models are an essential tool

It is comparatively easier to improve the Information Ratio of your portfolio by controlling your risk than by finding new sources of alpha, so a good risk model is an important tool for all portfolio managers. Most risk models use either a time series or cross-sectional approach. There are disadvantages to both.

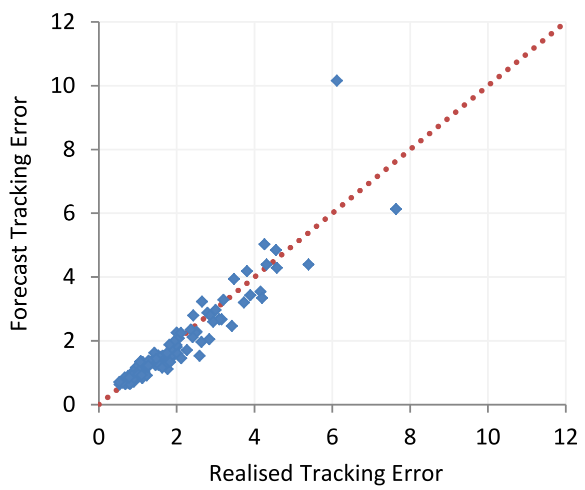
We argue for a hybrid approach to risk modelling

We argue that style risk factors are well suited to a cross-sectional approach, while market, region, sector and macro risk factors are better modelled with a time series approach. The UBS Hybrid Risk Model can incorporate both cross-sectional and time series risk factors.

Expectation Maximisation Algorithm & Bayesian priors

We use the Expectation Maximisation (EM) algorithm to estimate the UBS Hybrid Risk Model. This is guaranteed to be locally monotonically convergent so is a robust solution. By including Bayesian priors we may reduce sampling errors and will speed up the convergence of the EM algorithm.

Figure 1: Forecast versus realised tracking errors for US portfolios in 2020



Source : UBS

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Summary

Controlling risk is easier than finding alpha, and improves the Information Ratio of your portfolio

Finding alpha is difficult. Controlling your risk is comparatively easier and - all else being equal - a manager with better risk control will have a better Information Ratio than other managers. A well designed risk model is an essential tool for all portfolio managers.[1]

Controlling your risk means only having the exposures to risk factors that you intend to have. As a simple example, suppose you have identified ten stocks you believe will strongly outperform, but eight of them come from a single industry. A naive portfolio of those ten stocks will have the stock specific risk that you want, but also industry risk which, unless you also believe that industry will outperform, you don't want. If you don't control this exposure, a large negative return in the industry factor could easily destroy the alpha you anticipate from your single stock ideas.

Unintended exposures will often be much more subtle than this example, so a risk model is necessary to identify them. We find that clients are usually aware of the exposures due to the stocks in their portfolio, but sometimes neglect negative exposures due to e.g. underweighting certain styles, industries or countries.

Uses of risk models

Risk models are used in many areas of portfolio design and management. Here are the four main tasks investors use risk models for:

i. forecasting your tracking error; to summarise how risky your portfolio is in a single number
ii. risk attribution; to tell you what exposure the portfolio has to each risk factor
iii. performance attribution; to show which risk exposures explain the past performance of the portfolio
iv. optimisation; to create a portfolio which has a high expected return subject to constraints on, for example, total risk, number of stocks, sector exposures etc.

What is a good risk model? What are the trade-offs?

A good risk model is parsimonious, easy to understand, robust and accurately describes a portfolio's risk. Unfortunately, no risk model provides a perfect answer to all of these criteria. There are trade-offs:

- A risk model which is too parsimonious may not capture all of the important risk factors.
- A risk model with more intuitive, easy to understand factors may not be able to pick up new sources of risk.
- A risk model which imposes a lot of structure will have fewer parameters to estimate and so have a lower sampling error, but if the model has been misspecified it will have a high structural error.

UBS Hybrid Risk Model

We believe the UBS Hybrid Risk Model is an effective default model. It imposes enough structure to reduce the sampling error, but keeps enough flexibility to incorporate all the different sources of risk in a parsimonious fashion.

Our framework is flexible and allows portfolio managers to easily incorporate macroeconomic risk factors, such as the oil price, so they can see their portfolio's macro sensitivities.Our Hybrid Risk Model uses a cross-sectional approach for style risk, but a time series approach for other sources of risk. We believe this is a sensible response to differences in the characteristics of these sources of risk; a stock's exposure to style risk can change rapidly (for example, if its multiple changes) while its exposure to country or industry risk is fairly stable.

Combining these two approaches is technically challenging and requires the use of the Expectation Maximisation Algorithm, but users of the risk model should find it as easy to run and its output as easy to understand as any other risk model.

1. The authors would like to thank Professor James Sefton of Imperial College, London for the significant contribution he provided to this report.

Introduction to risk models

We start by describing what a risk model is, the three main types of risk models and some key assumptions. Then we discuss the trade-offs involved with building risk models, focusing on model accuracy but also considering parsimony and ease of interpretation. Finally, we discuss what we use risk models for and which type of risk model is most suited for each purpose.

What is a Risk Model?

Linear factor model

All risk modelling approaches are based on a linear factor model of the return generating process. This model can be written:

(Eq. 1) $$r_t = B_t f_t + \varepsilon_t$$

Where r denotes the n-vector of returns to the n assets at time t, f the k-vector of factor returns, B is the n by k matrix of factor exposures or betas and ε_t is the n-vector of residuals. The idea behind the linear factor model is that all the co-movement in returns can be captured by the k factor returns (where k is much smaller than n). This means that instead of having to estimate the full n by n covariance matrix, we only need to estimate the n by k factor exposures and the k by k factor covariance matrix. When there are a large number of assets, this drastically reduces the number of values to estimate.

To formalise this idea, assume that both f_t and ε_t are independently and identically distributed normal variates

(Eq. 2) $$f_t \sim N(0, F) \qquad \varepsilon_t \sim N(0, D)$$

To simplify the notation, we focus on risk only and assume that the random variables have zero mean. This is for convenience only - very similar models can be obtained with no such assumption made. The assumptions underpinning the linear factor model are that the error terms are uncorrelated with the factors and are independent, and so all the covariance in returns is explained by the k factors. Writing this mathematically we have:

(Eq. 3) $$Cov(f_t, \varepsilon_t) = 0 \qquad D = diag(d_1, d_2 \ldots d_n)$$

Given these assumptions, asset returns are normally distributed as

(Eq. 4) $$r_t \sim N(0, V_t) \ where \ V_t = B_t F B_t^T + D$$

The covariance matrix of returns, V_t is referred to as the risk matrix. "Building a risk model" just means estimating a covariance matrix of this form.

The Three Main Approaches to Risk Models

Time-series, cross-sectional and statistical risk models

There are the three main approaches to estimating a risk matrix, which we shall refer to as time-series, cross-sectional and statistical modelling.(2) All approaches use a sample of returns. However, they differ on the assumptions they make concerning the structure of the risk matrix.

Time-Series Risk Models: This approach assumes that the factor returns, f_t, are observed and that the factor exposures are constant, i.e. $B_t = B$. In practise, it uses either time-series of economic data or returns to factor-mimicking portfolios as proxies for the factor returns. The estimation problem is therefore reduced to estimating the constant factor exposures and residual covariance matrix, B and D respectively.

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2. Time-series models are often also called economic models, and cross-sectional models are sometimes referred to as random coefficients, fundamental or characteristic factor models.

Cross-sectional Risk Models: This approach assumes that the factor exposures, B_t, are observed, though in practise fundamental data is used as a proxy for these exposures. As the factor exposures are 'observed', they can vary over time. The estimation problem is reduced to estimating the factor and residual covariance matrices, F and D respectively.

Statistical Risk Models: This approach makes no additional assumption beyond the fact that there are k factors and the factor exposures and variances are constant over the sample period. Generally principal component analysis is used to identify the k factors from the return sample covariance matrix.

The UBS Hybrid model combines aspects of the time-series and cross-sectional approaches. We will discuss this in more detail later in the note.

Risk Model Assumptions

There are a few, key assumptions that these risk models make:

a) **There are k factors:** All of our modelling approaches require us to choose the number of factors in our model. If you have too few factors then the model will be overly simplistic and won't be able to capture the risk accurately. If we have too many factors then the model will be unnecessarily complex and so have a high sampling error. This also means that we may mis-attribute stock specific risk as factor risk. As a result you might use the wrong approach to control the risk in your portfolio.

b) **The factor betas are constant over time:** Both the time series and the statistical modelling approaches assume that the factor betas are constant over time.

This assumption is not totally correct. Andersen, Bollerslev, Diebold, Wu (2006), suggests there is a tendency for market, country and sector betas to mean revert over time. Some vendors specifically incorporate this tendency in their approach, by shrinking the historical market betas back to 1. The assumption is particularly flawed for stocks' betas with respect to style factors, as membership of these style baskets is very time-varying e.g. a stock may be a value stock at some point in time and then become expensive.

c) **The factor exposures are observable:** This is a very important - and flawed - assumption made by cross-sectional risk models for country and sector factors.

Cross-sectional models use an indicator dummy variable (which takes a value of 1 if the stock belongs to the market, sector or country and 0 otherwise) as a proxy for market, country and sector betas. This is implicitly saying that all stocks within a sector (or country) have the same sensitivity to sector (or country) risk. This is not correct. If we test that assumption empirically, we find it is rejected by the data at all standard confidence levels. We can try to remedy this by looking at more detailed sectors or smaller regions, but this increases the risk of over-fitting.

Trade-offs when building a risk model

What is the best approach to building a risk model? As always, there is no simple answer. Each approach offers a different balance on a number of objectives or trade-offs. We discuss three of these design trade-offs below:

Trade-off 1: Structural versus Sampling error

When estimating a large risk matrix, we have to specify some structure to reduce the number of parameters that we need to estimate. How much structure to specify is not a straightforward question.

If we choose a risk model which imposes a lot of structure (for example a simple time series risk model) then we won't need to estimate as many parameters. This pushes down the sampling error. However, if the model has been mis-specified - for example if you omit an important factor - you will have a much higher structural error. For the greatest accuracy, you need to find a risk model which balances sampling error and structural error.[3]

3. This can be understood as the bias/variance trade-off that you see in many statistical modelling problems.

A number of papers, Tien and Pfleiderer (2005), Scowcroft and Sefton (2006) and Connor and Briner (2008), have examined the trade-off between structural and sampling error. In all their tests, they found that the time-series and cross-sectional models outperformed statistical models. This strongly suggests that some structure is absolutely necessary to reduce sampling errors. However, the tests were less conclusive in determining precisely how much structure should be imposed; in some tests the time-series models did better and in others the cross-sectional models outperformed.

It is sometimes claimed that statistical models are less likely to 'miss' any risk factors. Miller (2006) investigated this. He found that, in practice, statistical models are only successful in capturing risks which i) are long-lasting and ii) affect many stocks. These are the very sources of risk that are easier to identify and will be included in any well built structural model!

It is also sometimes believed that statistical models are a better short term model of risk because they have the flexibility to capture temporary changes in market structure. We disagree. With a shorter horizon your data sample is even smaller, demanding one should impose more structure rather than less to avoid massive sampling errors!

Though this covers the principal statistical trade-offs, there are other objectives which are more pragmatic in nature and concern the simplicity and ease with which the results can be interpreted.

Trade-off 2: Ease of Risk Attribution

Portfolio managers not only want to know the total aggregate risk of their portfolio, but they also want to attribute it to various sources. This decomposition adds more value, if the various sources of risk – the factors – have an intuitive economic interpretation. For example, if one of the factors is associated with the oil price, then the portfolio exposure to this risk factor can be interpreted as exposure to movements in the oil price. But by constraining the directions of risk to lie in certain 'intuitive' directions, you may be limiting the ability of the risk model to pick up transitory or new sources of risk.

Trade-off 3: Parsimony

Reducing the complexity of the model amounts to keeping the number of factors to a minimum. This reduces the risk of over-fitting the returns but may mean a model does not capture an important risk factor.

What do you use a risk model for? Which risk model is best for each purpose?

Investors use risk models for many different purposes. There is no one type of risk model which is "best" every time. It depends on what you are trying to do with it.

Here are some common uses and some comments on which of the three basic types of risk model would be most appropriate:

i) Forecasting your tracking error

Short-term models can react quickly to big changes in market volatility, so are often preferred for forecasting your tracking error. This is fine for a statistical model, which will typically work well even with a shorter sample period (e.g. 6 months).

However, for the cross-sectional and time series models, this is a problem. For the time series model you will usually need a longer time period (e.g. 3 years' of data) to estimate coefficients accurately. For cross-sectional models, you typically have a large number of factors, which means you need a longer time period to estimate the covariance matrix robustly.

ii) Risk attribution

A risk model can help investors to break down the risk of their portfolio into a few, economically intuitive factors. A good risk attribution is parsimonious, easy to understand and robust.

Cross-sectional risk models typically have a very large number of factors - often as many as 80 - so it can be hard to fully understand the results of a risk attribution. However, the cross-sectional approach is very robust. If you analyse the same portfolio twice, a few weeks apart, you can expect to see a similar risk attribution each time.

In contrast, a time series risk model has a much more manageable number of easy-to-understand factors, because you can use the variation in stocks' betas to capture differences in their returns rather than relying on more and more subsectors or sub-regions. However they can have problems with robustness if there are outliers in the betas computed. This is traditionally handled by simple rules of thumb like capping betas at +/-1.2. Alternatively, you can use a Bayesian approach which shrink betas back to more plausible values (which is what we do in our UBS Hybrid Risk Model).

Statistical risk models are not appropriate for risk attribution. Statistical risk factors don't have an obvious real world interpretation, so if a risk attribution reveals a large risk exposure, it is hard for a portfolio manager to know if the exposure is desirable or needs to be controlled.

On balance, we recommend a time series model for risk attribution.

iii) Performance attribution

Statistical risk models are not suitable for performance attribution. We need intuitive factors for this attribution to be useful.

By construction, cross-sectional risk models have more stable betas than time series risk models. Performance attribution needs stable betas to make sense, so this is an advantage to cross-sectional risk models.

and iv) Optimisation

A risk model must be well conditioned for optimisation to work. If your risk model is mis-specified and doesn't capture all of the relevant risk factors then the optimisation algorithm will give a very large weight to stocks (or groups of stocks) which, due to failures of the risk model, appear to be very low risk, but which are actually of normal or even high risk. This is called the error maximisation problem.

To avoid this issue we need to be able to audit our risk model and check if it is well conditioned. That rules out statistical risk models. It is slightly easier to audit a risk model with a smaller number of factors, so a time series risk model or the UBS Hybrid Risk Model has a slim advantage over the cross-sectional risk model.

A digression: if you are using your risk model for optimisation, it is helpful for the risk factors in your risk model to align with your alpha factors. Modern Portfolio Theory (MPT) argues that in an optimal portfolio the marginal return from a position should equal the marginal risk from a position. This process is both easier and more robust if the risk factors align with the alpha factors. If the risk factors only align approximately with the alpha factors, then an optimiser will focus on a portfolio of stocks that have a positive return, but carry little risk. The optimiser will tend to gear up on such portfolios. This may lead to an unbalanced portfolio and certainly excess turnover. This problem is avoided if the alpha factors are included as risk factors.

The UBS Hybrid Risk Model

As we have seen in the introduction to risk models, we need to impose some structure on the risk matrix in order to limit the likelihood of significant estimation errors. But what structure? We believe this depends on the source of risk. For some sources of risk a cross-sectional model makes most sense, but for others a time-series model appears more reasonable. The UBS Hybrid Risk Model combines these two approaches. We choose which approach to use depending on the source of risk.

A list of possible sources of risk would inevitably include:

1. Market Risk – the systematic component of risk.
2. Macroeconomic risk factors e.g. commodity prices.
3. Industry Risk – risks that are systematic to a particular industry.
4. Regional or Country risk – risks that are systematic to a particular geographical area.
5. Style risk – risks that are pervasive to stocks that share a common characteristic; such as high debt, high earnings growth potential, heavily capitalised etc.

It is our view that the first four sources differ crucially from final one and need different approaches within a risk model.

Combining the cross-sectional and time-series approaches

Estimate industry and region/country betas with a time series approach

We believe that style risk factors should be handled differently to other risk factors. Whether a stock is a member of an industry or geography only very rarely changes. It is therefore reasonable to assume that exposures to these risk factors remain relatively constant over time. Furthermore the industry or country factor returns can be well proxied by the respective index returns. We therefore argue it is more natural to estimate these factors in time-series; i.e. assume that we observe the factor returns and estimate the exposures. Our reasons are summarised in the following list:

- Estimating these factors in time-series allows for a more parsimonious description of the risk. Heterogeneity in sensitivities can be accommodated by heterogeneity in betas rather than the introduction of more risk factors. For example, global universal banks have a tendency to be more sensitive to financial shocks than local retail banks. In a cross-sectional model we would have to model this by having two factors, one for each sub-sector, with the factor returns being highly correlated but with one having a higher volatility than the other. In a time-series model, we could do that, or we could use a single factor with the stocks having differing sensitivities to this single factor.
- The time series approach can accommodate cross-sensitivities between sectors and countries. Thus export orientated companies can have some sensitivity to foreign markets as well as their own domestic market. Similarly, companies with business lines which span multiple sectors can have exposures to multiple sectors, not just the one sector the overall company is assigned to.
- Macroeconomic factors can only be easily incorporated in a risk model using a time-series approach. Given an economic series – e.g. oil prices – it is straightforward to estimate stock sensitivities within a time series regression. It is not immediately obvious how this could be done within a cross-sectional model.

Estimate factor betas with a cross-sectional approach

In contrast to the first four sources of risk, sensitivity to style risk is likely to vary over time. For example, a stock's exposure to the risk associated with heavily indebted companies will change if it has a major capital restructuring, its exposure to the risk associated with very cheap companies will change if its multiple changes, etc. If we have a reasonable proxy for these time-varying exposures - such as the style values themselves - then the time-varying nature of these sensitivities can be accommodated relatively easily within a cross-sectional framework. We therefore believe style factors are better estimated in a cross-sectional framework.

We therefore suggest the following hybrid approach to estimating a risk model:

- For market, economic, industry and country factors, use a time-series approach. More precisely, assume the risk factor returns, f_t, are well proxied by the returns to the respective market, economic, industry and country indices. Then – under the assumption that the betas are constant over the sample – estimate the parameters using a number of time-series regressions. As this means estimating a relatively large number of parameters, we will estimate them within a Bayesian framework. This effectively shrinks the least-squares estimates back to a set of prior values – either '1' or '0' – but in proportion to the degree of uncertainty. Thus if the parameter is poorly estimated (as measured by its t-stat or sample variance) then it is shrunk back heavily. Conversely, if it is well estimated then far more weight is placed on the estimate.

- For style factors, we use a cross-sectional approach. Assume that we observe the time-varying exposures B_t and estimate the factor returns, f_t, using a series of cross-sectional regressions.

We refer to this model as UBS Hybrid Risk model.

Estimating the UBS Hybrid Risk Model

Combining the time series approach and the cross-sectional approach is not completely straight forward. In the time series and cross-sectional approaches, we assume that we know one of i) the factor exposures and ii) the factor covariances, and use these to compute the other. In the hybrid approach, we are explicitly saying that we don't know either of these for the full list of our factors.

We use the Expectation Maximisation algorithm (EM) to solve this issue. We defer most of the detail of this model to the Appendix, but give a (very) brief sketch of the algorithm below.

We need some initial estimates for:

i. the betas to time series risk factors (market, country, sector and macro factors). This will just be the time-series betas, which we can compute by regressing the returns data on the returns to the market, country and sector index returns and onto macro time series.
ii. the volatility of the error terms. This will be the volatility of the underlying assets.
iii. the inverse of the covariance matrix for the cross-sectional risk factors (the style factors). We initially estimate this as the zero matrix.

Then we iterate between the following two steps until our parameters converge:

1) Given our current estimate for the time series risk exposures, we can estimate the unobserved cross-sectional factor returns for each period. This gives us a new estimate for the covariance matrix for the cross-sectional factors (and its inverse).

2) Given this new estimate for the cross-sectional factor returns we can calculate a new estimate for the time-series exposures.

The EM algorithm has a number of very desirable properties. The principal being that it is guaranteed to converge monotonically to a local maximum. This is a reliable solution to estimating the UBS Hybrid Risk Model.

Accuracy of the Hybrid Risk Model

In order to test the accuracy of the UBS Hybrid Risk Model we have compared the forecast tracking error with the realised tracking error over the following year for a large number of portfolios.

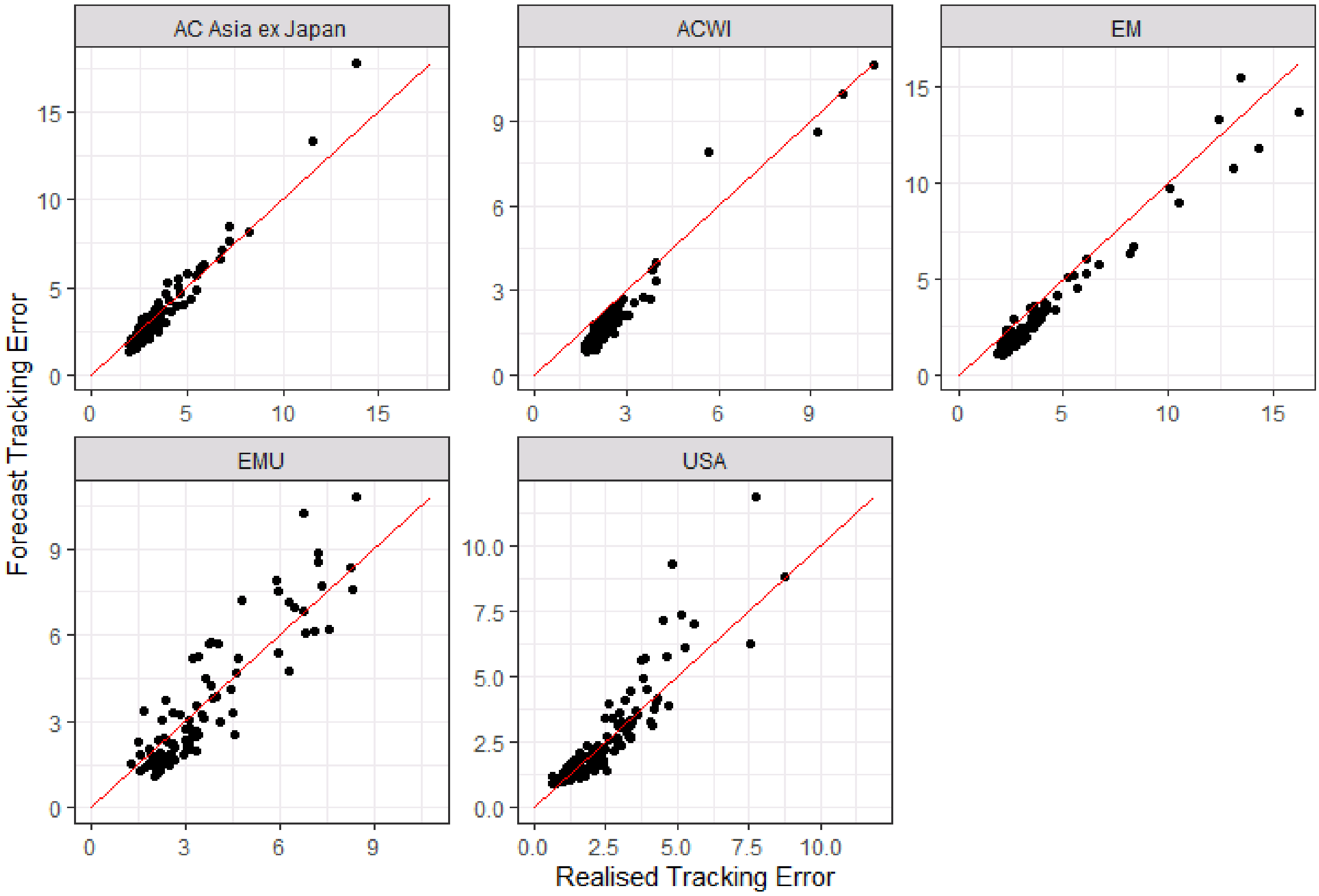
To do this, we needed some randomly generated portfolios. We generated these using a simple algorithm:

- Randomly select 35% of the stocks from each sector.
- For each stock choose a value uniformly from the range 0 to 1, and multiply its market cap by this random value. These figures are then normalised so that each sector sums to 100%. This gives us the weight of each stock in the portfolio within its sector. These will typically be larger for large-caps but small and mid-cap names can still potentially take a substantial weight.
- Each stock's weight within its sector is then multiplied by the weight of its sector in the benchmark to give the stock's weight in the overall portfolio. This yields a sector neutral portfolio.

We repeat this procedure 100 times to generate 100 random portfolios. We can then use the UBS Hybrid Risk Model to compute the forecast tracking error for each portfolio and then, by looking at the returns over the following year, we can compute the actual realised tracking error for each portfolio. This lets us see how accurate the risk model's forecasts are. We have run this analysis for various different regions and time periods.

We start by examining forecasts tracking errors for 2013 for five different regions; ACWI, EMU, the USA, AC Asia ex Japan and the Emerging Markets. We chose 2013 as an example of a fairly uneventful year from a macro perspective. The risk model would have been reasonably accurate.

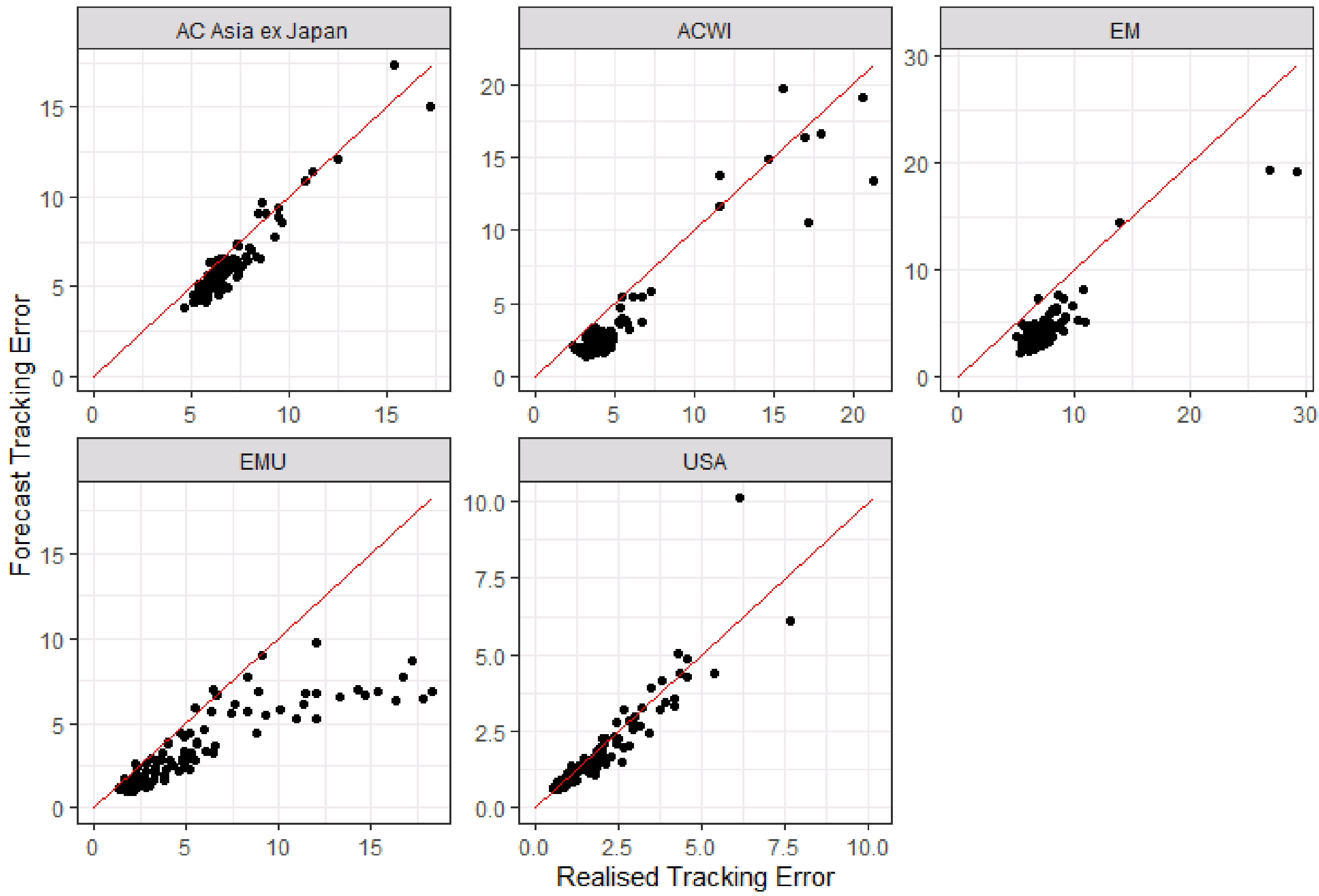
Figure 2: Comparison of forecast and realised tracking errors in 2013



Source : UBS

If we examine 2020, we see that the UBS Hybrid Risk Model somewhat under-forecast risk in most of these regions. This is not very surprising. 2020 was a highly volatile year with a large jump in an unforeseen macro factor - the pandemic.

Figure 3: Comparison of forecast and realised tracking errors in 2020



Source : UBS

Do Style Factors Add Explanatory Power to the Hybrid Risk Model?

The Hybrid model is built with 8 style risk factors; value (earnings yield), earnings momentum, 1-month and 6-month price momentum, size, volatility, quality (ROE) and a capital gearing factor (net debt to EV). In this section we investigate the explanatory power or significance of each style. We then compare the estimated style returns from both the Hybrid and Cross-sectional models with a set of calculated style index returns.

We want to test whether a factor adds to the explanatory power of the risk model. If it does not, we could drop the factor and achieve a more parsimonious description of the data. However, a little care is required. As we have estimated the model in a Bayesian framework, we cannot use classical hypothesis tests. Instead we must approach the question, by asking whether one model description is more likely than another. Both the Bayesian Information Criterion (BIC) and the Akaike Information Criterion (AIC) offer an approach based on these lines. Similar to the classical likelihood ratio test, the criteria are based on twice the likelihood. However the criteria make an adjustment for the number of estimated parameters. These criteria therefore quantify the trade-off between the model fit and parsimony. The preferred model is the one with lowest information criterion. The BIC tends to favour less complex models than the AIC. These statistics are discussed in Lopes and West (2004). They argue that BIC is to be preferred.

Figure 4: Testing the parsimony of the Cross-Sectional Factors

	Base Model	Drop Value	Drop Earnings Momentum	Drop Price Momentum	Drop Market Cap	Drop 12 mth Volatility	Drop Quality	Drop Leverage
Log Likelihood	4712.2	4686.7	4687.4	4691.0	4699.3	4702.2	4703.2	4704.6
BIC	50229.1	50267.6	50266.1	50259.0	50242.4	50236.5	50234.5	50231.7
Difference in BIC	0	38.5	37.1	29.9	13.3	7.4	5.4	2.7
AIC	57671.7	57708.6	57707.2	57700.0	57683.4	57677.5	57675.5	57672.8
Difference in AIC	0	37	35.5	28.3	11.8	5.9	3.9	1.1
Volatility		7.21	3.97	5.49	2.45	3.55	1.84	1.85

Source : UBS. Each column refers to a different model. The first column is our default model with all the 7 factors included. The remaining 7 columns drop each of these factors in turn. The first row records the value of likelihood function at the optimum, the second row the BIC, and the 3rd row the difference in the BIC statistic from that of default model (all factors included). The 4th and 5th row record similar statistics for the AIC and the final row gives the estimated volatility in the default model of the dropped factor returns.

All of the style factors improve the risk model; value, size and momentum contain the most information

Figure 3 records the results from the first set of experiments. In the default model there are 7 cross-sectional style exposures. We drop each of these factors in turn, and test whether this reduced factor model is more informative. We shall focus our discussion on the BIC statistics. The number of estimated parameters, p, in each model is nk_{TS} time-series exposures, n idiosyncratic return variances and $k_{XS}(k_{XS}+1)/2$ independent parameters in the cross-sectional covariance matrix; the BIC is equal -2l+p.log(T) where l is the log likelihood and p is the number of parameters. A model with a lower BIC is more probable in a Bayesian sense. Of all the models, the default model has the lowest BIC and so is suggestive that all the factors should be included. However the criterion does rank the factors in some order of explanatory power. The value, momentum and size factors contain the most information, with volatility, quality and leverage the least. The results from the AIC are consistent with these findings.

We have also recorded in the table the volatility of the estimated factor returns in the default model. Perhaps unsurprisingly, the volatility of the factors ranks the factors in almost the same order as the information criteria.

A Comparison of the Hybrid Risk Model and Cross-sectional Risk Model

Ideally, we would try to establish if this UBS Hybrid Risk Model is better than previous standard approaches. Unfortunately, this is not possible as there is no single discriminating test. Instead we must be content with a comparing our Hybrid model to a ‘close’ cross-sectional relative. Our comparison is designed to highlight the principal differences between the two approaches. We take the various components of the model in turn, examining industry and regional exposures, industry and regional factor returns and finally the style returns.

Details of the comparison model

We start off by describing the comparison model. We shall refer to this model as the cross-sectional model though this is not an entirely accurate description for reasons we shall now explain. This cross-sectional model has the same set of factors as our Hybrid model; a market factor, 7 regional factors, 10 industry factors and 7 style factors. These are estimated as follows:

1. **Market Factor:** Firstly the market beta or exposures are estimated. This is done in time-series by regressing each stock return series on the market returns and a constant. The coefficient on the market is then the market beta. The rest of the model is estimated on the residuals of the regression rather than the raw returns. It is for this reason that even our cross-sectional model can be regarded as a sort of Hybrid model.
2. **Regional, Industry and Style Factors:** In a cross-sectional model, all exposures are assumed to be known a priori. The country and industry exposures are the indicator vectors – an element is 1’ if the stock lies in the respective industry or country and ‘0’ otherwise – and the style exposures are proxied by a fundamental ratio. Thus in this cross-sectional model the country and industry exposures are the Bayesian priors used in the Hybrid model, and the style exposures are identical to those in the Hybrid model. Given these exposures, the factor returns are estimated by regressing the stock returns net of the market on these exposures in each period. Both our Hybrid

and the Cross-sectional Model are estimated on the MSCI Investible Market Index (IMI) for developed markets of large and medium sized companies. The universe is just over 1600 stocks in each period. The models are estimated on 5 years worth of monthly data – i.e. 60 monthly observations.

Comparison of Industry Factor Estimated Returns

We shall now compare the industry factor returns estimated in the cross-sectional model with those used in the Hybrid model (recall that the factor returns used in the Hybrid model are the returns to the respective indices). The results are given in Figure 2. The first column records the correlation coefficient between the respective time series; the second and third columns the annualised volatility of the two series. The industry volatilities of the two sets of factors returns are broadly similar.

Figure 5: Comparison of the estimated factor returns from the cross-sectional model with the respective index returns used within the Hybrid model.

	Correlation of factors returns - Hybrid vs. Cross-sectional models	Annualised Volatility of Factors Returns for the Hybrid Model	Annualised Volatility of Factors Returns for the Cross-sectional Model
Oil & Gas	0.94	16.10	12.83
Basic Materials	0.68	12.85	6.63
Industrials	0.60	5.23	5.34
Consumer Goods	0.63	4.25	4.29
Health Care	0.81	7.85	5.66
Cons. Services	0.78	5.68	5.53
Telecomms	0.81	7.44	6.75
Utilities	0.78	7.56	6.30
Financials	0.79	7.74	6.72
Technology	0.64	9.49	7.63

Source : UBS

Comparison of Style Factor Estimated Returns

We now compare the estimated cross-sectional style returns from the Hybrid model with those from the Cross-Sectional model, with a set of calculated style returns. These calculated style returns are returns to a set of long short factor mimicking portfolios.

Each period we divide our universe into industry and regions (e.g. North American Utilities). Within these sub-groups we rank stocks according to the relevant style beta. The top third of names within each sub-group is then our high basket and the bottom third of names is our low basket. The equally-weighted industry and regionally neutral style portfolio is defined as long the high basket and short the low basket. The style return is the return to this portfolio.

Figure 4 records the correlation coefficients between the various style return series. For the Hybrid model, we have estimated the style returns with τ (the confidence placed in the prior) set to 1, which is its default value.

Figure 6: Correlation coefficients between respective style return series

	Value	Earnings Momentum	Price Momentum	Market Cap	12 mth Volatility	Quality	Leverage
Calculated returns vs hybrid model factor returns	0.83	0.84	0.49	0.72	0.88	-0.29	0.68
Calculated returns vs cross-sectional model factor returns	0.82	0.66	0.77	0.76	0.91	0.34	0.58
Hybrid model factor returns vs cross-sectional model factor returns	0.87	0.88	0.84	0.71	0.88	0.55	0.72

Source : UBS

We make a couple of observations based on the results in this table:

1. The estimated factor returns of the Cross-sectional and Hybrid models are highly correlated.
2. The correlation of the estimated factor returns with the calculated style returns is low

for the quality style. This may be because this style is relatively uninformative and therefore poorly estimated.

Conclusion

In this paper we have argued for a Hybrid approach to building a risk model. We maintain that this imposes sufficient structure so as to reduce sampling error, but retains the flexibility to incorporate all major sources of risk in a parsimonious fashion.

Our Hybrid model assumes the respective index returns are a good proxy for the industry and country risk factors. We prefer to estimate the betas, in the belief that there is substantial heterogeneity in these exposures both within and across sectors and regions. Furthermore this framework can incorporate macroeconomic risk factors naturally.

In contrast, we prefer to estimate style factors in cross-section. Here the major attraction of a cross-sectional approach is that betas can vary over time. This is critical since style membership varies from period to period.

Appendix

Further Details on the Estimation of the UBS Hybrid Model

We want to estimate style factors using the cross-sectional approach and the other risk factors using a time-series approach. Combining these two approaches means that we cannot assume that we fully know either the factor exposures or the factor covariances. This makes estimating the covariance matrix and factor exposures more challenging.

The estimation procedure builds on the work of Stroyny (2005). However, we develop his approach in a number of ways. Firstly, and most crucially, we incorporate priors on some of the parameters, in particular the time-series beta exposures. This generalisation is not only likely to reduce sampling error, by shrinking back the parameters that are poorly estimated, it also speeds up significantly the estimation procedure.[4]

Our second generalisation is to allow for stochastic nature of the factor returns in the estimation procedure. Some of the early work on factor analysis, Young (1942) and Lawley (1943), treated the factor returns as additional model parameters. The resultant algorithm – often referred to as the Least Squares Method of Factor Analysis (LSMFA) – was straightforward in that it amounted to iterating over a standard set of least squares regressions. However, Whittle (1952) described the approach as "too unstable to be useful". Rubin and Thayer (1982) suggested using a prior that the factors returns were drawn from a normal distribution, and showed that the resultant model could be estimated using the Expectation Maximisation Algorithm, see McLachlan, Krishnan (1997). Adapting the Rubin and Thayer (1982) to our problem has three direct payoffs:

1. It stabilises the estimation algorithm.
2. It ensures that our estimated style factors are both industry and regionally neutral.
3. It ensures that our estimate of the factor covariance matrix takes due account of errors in the estimation of the style factor returns.
4. It enables us to test in turn whether each factor significantly adds to the explanatory power of the risk model.

Let us describe the estimation procedure in greater detail than we did in the main note. Recall the basic linear factor model framework:

(Eq. 1) $r_t = B_t f_t + \varepsilon_t$

(Eq. 2) $f_t \sim N(0, F) \qquad \varepsilon_t \sim N(0, D)$

(Eq. 3) $Cov(f_t, \varepsilon_t) = 0 \qquad D = diag(d_1, d_2 \dots d_n)$

(Eq. 4) $r_t \sim N(0, V_t) \; where \; V_t = B_t F B_t^T + D$

We re-write equation (1) to separate out the time-series factors from the cross-sectional factors:

(Eq. 5) $r_t = [B_{TS} \quad B_{XS,t}] \begin{bmatrix} f_{TS,t} \\ f_{XS,t} \end{bmatrix} + \varepsilon_t$

where the subscript TS or XS denote the factors estimated in time-series and cross-section respectively. We assume that we observe the time-series factor returns, $f_{TS,t}$, and the cross-sectional betas, $B_{XS,t}$ and must estimate the timeseries betas, B_{TS}, and the covariance matrices, D and F. We estimate the risk model in a Bayesian framework in an effort to reduce sampling error. We assume a standard conjugate on the time-series

4. These two advantages are closely related. If a parameter is poorly estimated, its value is likely to 'jump' between iterations. By shrinking these parameters back to their priors, one not only reduces estimation error, but stabilise the iterative estimation procedure.

betas,

(Eq. 6) $$Vec(B_{Ts}) \sim N\left(Vec\left(B_{TS,0}\right), \tau\Omega\right) \text{ where } \Omega = diag(vec(\Lambda))$$

where the $B_{TS,0}$ is the dummy indicator matrix described earlier (an element is '1' if the stock lies in the respective industry or country, and is '0' otherwise), Ω is a diagonal matrix of variances and τ is a scalar. In our default model, we set τ =1. Later we experiment with different values for τ , so as to investigate the sensitivity of the parameter estimates to our prior. The matrix Λ has the same dimensions as B_{TS} with elements equal to the variance of the prior estimate. We calibrate these priors using a simple rule of thumb; imagine estimating a single beta by regressing a vector of factor returns on a vector of a stock's returns. In this case, the standard error of the beta estimate will be:

(Eq. 7) $$Var\left(\hat{b} - b\right) = \frac{Var(\varepsilon)}{TVar(f)}$$

where the notation should be clear from above. Using typical values of Var(ε)/ Var(f) = 4, then with 60 observations the variance of the beta estimate should be 0.25. Based on this, in the default model we let Λ =(0.12+0.13 $B_{TS,0i}$). Hence if the mean of prior is a '1', its standard deviation (std.) is 0.5 (or variance of 0.25) and if the mean of the prior is '0' its std. is 0.35. Thus our prior belief is that 95% of stocks have betas with respect to their industry or geography in the range 0 to 2, and betas in the range -0.7 to 0.7 with respect to the other factors.

The estimation procedure is based on an Expectation Maximisation (EM) algorithm. To describe the approach, it will prove useful to write the covariance matrix F in diagonal form where:

(Eq. 8) $$F = \begin{bmatrix} F_{TS} & 0 \\ 0 & F_{XS} \end{bmatrix}$$

so that F_{TS} is the covariance matrix of the times-series factor returns:

(Eq. 9) $$F_{XS} = \frac{1}{T}\Sigma_t f_{TS,t} f_{TS,t}^T$$

and F_{XS} is the covariance matrix of the cross-sectional factor returns. The EM algorithm is an iterative procedure can now broken down into the following steps:

1. Scale all returns by an estimate of market volatility for that period. This removes a considerable proportion of the observed hetereoskedascity in returns. Initialise the estimation procedure with B_{TS} = $B_{TS,0}$,D=diag(Cov(r)) and F_{XS}^{-1}=0.
2. Given an estimate for B_{TS}, D and F_{XS}^{-1} calculate an estimate for the unobserved cross-sectional factor returns, $f_{XS,t}$ as

(Eq. 10) $$\hat{f}_{XS,t} = \left(B_{XS,t}^T D^{-1} B_{XS,t} + F_{XS}^{-1}\right)^{-1} B_{XS,t}^T D^{-1}(r_t - B_{TS} f_{TS,t})$$

with variance

(Eq. 11) $$Var\left(\hat{f}_{XS,t} - f_{XS,t}\right) = \left(B_{XS,t}^T D^{-1} B_{XS,t} + F_{XS}^{-1}\right)^{-1}$$

for every period t. Given these, a new estimate of the covariance matrix F_{XS} is

(Eq. 12) $$F_{XS} = \frac{1}{T}\Sigma_t(\hat{f}_{XS,t}\hat{f}_{XS,t}^T + Var(\hat{f}_{XS,t} - f_{XS,t}))$$

3. Given the estimate for the cross-sectional factor returns for $\hat{f}_{XS,t}$ calculate a new estimate for the time-series exposures, B_{TS},. This is done asset by asset, effectively performing n time-series regressions. If we use the notation $[X]_{i\bullet}$ to refer to the i[th] row of the matrix X then:

(Eq. 13) $[B_{TS}]_{i*} = \left(\sum_t s_t^{-2}(r_{t,i} - [B_{XS}]_{i*}\hat{f}_{XS,t})f_{TS,t}^T + [B_{TS,0}]_{i*}Z_i\right)$
$\left(\sum_t s_t^{-2} f_{TS,t} f_{TS,t}^T + z_i\right)^{-1}$

where Z_i is a diagonal matrix with the j[th] element on the diagonal equal to σ_i^2/Λ_{ij} . Finally we update the estimate for the variance of the residual returns as

(Eq. 14) $D = \frac{1}{T}\Sigma_t\left(\left(r_t - B_{TS}f_{TS,t} - B_{XS,t}f_{XS,t}\right)\left(r_t - B_{TS}f_{TS,t} - B_{XS,t}f_{XS,t}\right)^T + B_{XS,t}Var(\hat{f}_{XS,t} - f_{XS,t})B_{XS,t}^T\right)$

4. Given these updated estimates of the parameters go to step (2). Repeat the loop until the parameters converge.

The EM algorithm has a number of very desirable properties. The principal being that it is guaranteed to converge monotonically to a local maximum. The convergence can be slow but is stable. In practise, we found that with relatively confident priors, $\tau < 100$, convergence was surprisingly fast. The priors shrunk back the poorly estimated parameters – the very parameters that would converge slowly if the priors were diffuse – which dramatically sped up convergence.

Effect of Bayesian Framework on Hybrid Risk Model

The UBS Hybrid Risk Model uses a Bayesian framework to speed up the computation of the EM algorithm and to improve the robustness of the model by avoiding extreme outliers in the betas. In this section, we examine the impact of our priors and the certainty (τ) that we place on them.

In the default risk model, there are 7 regional factors – US, UK, Canada, Japan, EMU, Europe ex UK ex EMU, Asia ex Japan – and 10 industry factors – the ICB industry groups. The Hybrid model uses as its prior for the regional and industry exposures the indicator vectors; an element is 1' if the stock lies in the respective region or industry and '0' otherwise.

In the following table we assess the impact of these priors. The table is split into two. The left hand side gives results for the case $\tau = \infty$ i.e. a very diffuse prior and the right hand side when $\tau = 1$ i.e. a strong prior, this is the default value for τ in the risk model. As τ tends to infinity, less and less weight is given to the priors, and in the limit the posterior estimates tends towards the same values that would be derived from a least square regression. The 1st column gives the mean of beta for all stocks belonging to the industry or region of that factor. The 3rd column gives the mean of the other beta estimates. The 2nd and 4th columns give the average standard deviation of the corresponding estimates around the means. Columns 5-8 give the same information for the posterior estimates for when $\tau = 1$.

Figure 7: A summary of the exposure estimates for each of the industry and region

	Diffuse Prior ($\tau = \infty$)				Conjugate Prior ($\tau = 1$)			
	Stocks within Industry or Region		Stocks not in Industry or Region		Stocks within Industry or Region		Stocks not in Industry or Region	
	Mean Beta	Std. Dev of Beta	Mean Beta	Std. Dev of Beta	Mean Beta	Std. Dev of Beta	Mean Beta	Std. Dev of Beta
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Oil & Gas	0.83	0.55	0.10	0.49	1.01	0.31	0.04	0.18
Basic Materials	0.77	0.68	0.05	0.45	0.82	0.46	0.03	0.23
Industrials	0.92	0.94	0.20	0.78	0.87	0.35	0.03	0.18
Consumer Goods	0.55	0.90	0.12	0.86	0.84	0.31	0.03	0.18
Health Care	0.67	0.80	0.09	0.65	0.81	0.31	0.02	0.18
Consumer Services	0.85	0.78	0.21	0.76	0.90	0.32	0.04	0.18
Telecommunications	0.65	0.54	0.03	0.63	0.87	0.29	0.01	0.18
Utilities	0.92	0.63	0.14	0.60	0.93	0.32	0.05	0.20
Financials	0.74	1.28	-0.02	1.00	0.74	0.35	-0.03	0.16
Technology	0.76	0.89	-0.03	0.57	0.81	0.44	-0.01	0.19
Canada	0.59	0.67	-0.09	0.63	0.88	0.25	0.01	0.18
UK	0.69	0.85	-0.15	0.82	0.80	0.34	-0.02	0.17
Japan	0.90	0.66	-0.13	0.50	0.94	0.38	-0.02	0.17
United States	1.14	0.94	0.14	0.40	1.02	0.11	0.01	0.04
EMU	0.70	0.93	0.02	0.77	0.94	0.28	0.01	0.14
Europe Ex EMU & UK	-0.05	0.76	-0.08	0.68	0.73	0.27	0.01	0.16
Asia Pacific Ex Japan	0.59	0.70	-0.17	0.63	0.85	0.27	-0.02	0.18

Source : UBS, The first four columns summarise for case tau = ∞, the last four for the case tau = 1. Each line refers to the beta estimates with respect to that factor. We record the mean and standard deviation of the betas for two groups of stocks; a stock is in the first group if it belongs to the respective industry or region and in the 2nd group if it does not.

There are number of clear conclusions from these results:

1. The mean beta of stocks to their own industry or region is close to but slightly less than 1. The mean beta of stocks to other industries or regions is clearly centred on 0. This is a very significant difference.
2. When the prior is diffuse, the standard deviation within each group of the beta estimates is high. For the first group, it is roughly 0.75. Comparing columns 2 and 5, the impact of strengthening the prior is clear. The prior shrinks the estimates back, reducing the standard deviation of the posterior betas by over half.
3. There is some evidence that the industry exposures are more significant than the regional exposures. This comes from comparing the ratio of the standard deviation of the members' beta for the two different models (i.e. column 1 / column 2 or column 5 / column 6)

References

Andersen, T. G., Bollerslev, T., Diebold, F. X., and Wu, J. (2006), “Realized Beta: Persistence and Predictability.” in T. Fomby, ed., Advances in Econometrics: Econometric Analysis of Economic and Financial Time Series.

Fama, E.F. and French, K.R. (1992). “The cross-section of expected stock returns”, Journal of Finance, 47(2), 427-465.

Heston, S.L. and Rouwenhorst, K.G. (1995). “Industry and country effects in international stock returns, The Journal of Portfolio Management, 21(3), pp. 53-58.

Tien, D. and Pfleiderer, P. and Maxim, R. and Marsh, T. (2005). “Decomposing Factor Exposure for Equity Portfolios” in ‘Linear Factor Models in Finance’..

Scowcroft A., Sefton J. (2006). “Understanding Factor Models”, UBS Global Quantitative Research.

Briner, B.G. and Connor, G. (2008). “How much structure is best? A comparison of market model, factor model and unstructured equity covariance matrices”, Journal of Risk, 10(4), pp. 3-30.

Miller, G. (2006). “Needles, Haystacks, and Hidden Factors”, The Journal of Portfolio Management, 32(2), pp. 25-32.

Stroyny, A.L. (2005). “Estimating factor models” in Linear Factor Models in Finance, pp. 210-215.

Young, G. (1940) “Maximum likelihood estimation and factor analysis”, Psychometrika, 6, pp. 49:53.

Whittle, P. (1952) “On principal components and least squares methods of factor analysis” Skandinavisk Aktuarietidskrift, 36, pp. 223-239.

Rubin, Donald B. and Dorothy T. Thayer. (1982), “EM Algorithms for ML Factor Analysis.” Psychometrika, 47, pp. 69-76.

Lawley, D. N. (1941). “Further investigations in factor estimation”. Proc. Roy. Soc. Edinburgh Sec. A, 61, pp. 176-185.

McLachlan, G.J. and Krishnan, T. (1997). “The EM algorithm and extensions”, Wiley, New York.

Connor, G. Korajczyk R. (2009). “Factor Models in Portfolio and Asset Pricing Theory”, http://ssrn.com/abstract=1139062.

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